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THE INFLUENCE OF LEARNING STRATEGY AND PERFORMANCE STRATEGY UPO--ETC(U)

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JUL 77 R BAILEY, G PASK

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(2) Abstract continued.

report. Research plans are briefly discussed in the final sections of the report.

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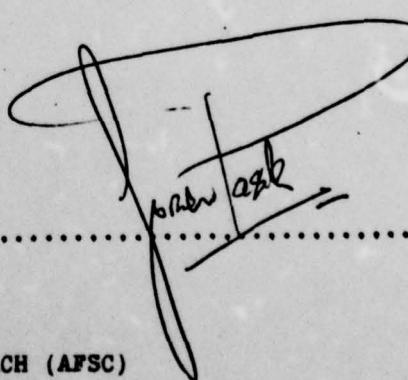
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1. INTRODUCTION AND SUMMARY OF PROJECT

The study of electronic engineering design and the influence of cognitive style upon design ability has been described in Reports 1 to 6 and Scientific Notes 1 and 2.

In summary, designers are sampled from two groups, A and B; namely, experienced designers and students who are skilled in electronics, but have little or no experience of designing on their own. The subjects are pre-tested using a lengthy, computer administered, test of learning style (Scientific Note No 1, and Progress Report No 6). The test is scored for operation learning (ability to construct procedures if a goal description is given), comprehension learning (ability to assimilate a general description, or construct it from other general descriptions, but not necessarily to realise the entities described) and versatility, which is an index of ability to predict, to plan and to realise plans. Versatility is correlated with a combination of both operation and comprehension learning (though, scorewise, it need not be) but involves additional creative or productive skills. Other subscores are calculated and other mental tests are administered, together with a background questionnaire, but the main prediction is that subjects with high versatility scores will design well.

All subjects engage in a many session design task which involves building up and trying out a breadboard prototype of a simulator for reaction kinetics and chemical equilibrium; used for classroom demonstrations. Any design must satisfy a brief and function properly, but it is regarded as desirable to maximise reliability and transparency, and to minimise environmental sensitivity, and cost/weight/fragility. Designs are evaluated according to these and other criteria, both by independent judges and the subjects themselves.

Of the two groups, nearly all experts show high versatility scores. Amongst the student group, there is greater variation and some of the student designers with lower versatility are given (whilst others are not given) specific versatility training, in the belief that it will improve their performance.

Behaviour during the design task is recorded conventionally (by sketches, comments, logging the concrete circuitry built up) but a more penetrating index of confidence is obtained, after each design session using a computer regulated interface, known as THOUGHTSTICKER (fully described in Progress Report No 4, and Progress Report No 6), through which the designer gives a standard-format, quantifiable explanation or justification of his design up to that stage in the task. This explanation or justification not only refers to the electronic circuitry, itself (a necessary feature), but also, very often, to the application domain; for example, relevant parts of theoretical physical chemistry and the problems likely to be encountered in demonstrating concepts or practical experiments with the aid of the simulator.

The format of the explanation and justification is graphical and called an entailment mesh (Scientific Note No 2, Progress Report No 6). The meshes which justify the completed design are finally described in a systematic manner which includes an assignment of values to the criterion variables (reliability, transparency, etc).

After completing the design task as individuals, the subjects are assembled into representative groups, with or without expert participants, and are presented with a further brief; to devise simulators for complex reactions in which the prototypes they have all (at this stage) manufactured are linked into networks and certain more detailed principles underlying reaction kinetics are demonstrated. The chief objective of the group sessions is to sample communication between designers, their activity as a team, and the influence of personal style and design performance upon their interaction. Individuals in each group

also explain or justify the group design (again using THOUGHTSTICKER) as seen from their own perspective. Finally, because standard-format explanations can be compared and quantified, the group task forms part of the evaluation of design-performance.

2. Progress Made

Considerable effort was expended upon finding a design task that would be considered "realistic" and, having done that, in removing "blocks" that led to unduly lengthy experimentation. The task, as finalised, occupies approximately 10 sessions and about 40/50 hours in the laboratory for expert designers, and 6/8 sessions or a total of 30/40 hours for student designers. The duration of the team task is variable; the group can be "fed" problems or "prompted" into further innovation as long as their behaviour remains coherent and reveals interesting features.

Up to date, 6 expert designer subjects and 9 (non pilot) student subjects have completed the individual task (reaction simulator) and, at the moment 4 further experts and 5 student designers are starting or in the process of design. 3 teams, (maximum, 4 members) are meeting periodically: though full attendance is not required, no teams have flagged through loss of motivation and it is intended to maintain the sample population by means of seminar-like meetings, for the studies described in our proposal EOARD-77-046 (which has recently received technical approval) some of which draw subjects from the already characterised pool.

3. Results Obtained

The data obtained in the course of the individual design task is exceptionally detailed (specimens of it are shown in Scientific Note No 2). The session by session data, as well as the final "entailment mesh" (that justifies, or explains, a subject's completed design), are open to numerical quantification in terms of complexity and connectivity (specimen calculations are shown as part of Progress Report No 6) and the descriptive evaluation of the final design, together with its justification, can be elicited not only from the designer responsible, but also from other subjects. Hence, various detailed and numerical cross comparisons are possible and noted, also, in Progress Report No 6.

The difficulty with such highly informative measures is that there is no economic way of using them until a full set of data is available from the individual design task subjects. At any rate, a proper analysis, to form the reference frame in which to make sense of team task data, cannot be obtained until all individual subjects have completed their assignment. We shall be able to run sample analyses about six weeks from this date (they will be presented, as soon as possible, in a Scientific Note No 3, containing details of the methods and computer programs employed). A full analysis of the individual designers should appear about one month after the next Progress Report No 8.

Using far less refined indices, based on counts of events, evaluative judgements of records, etc, some results can be stated at this juncture.

The subjects, whether experienced designers (Group A) or student designers (Group B) regard the brief as unusually comprehensive and detailed, but are prepared to accept it, with this caveat, as realistic. The expert designers recognise the need to think ahead about the application domain from the outset and typically adopt a global perspective during the 1st session;

for example, most of them start out by defining the subproblems of computing rates and computing heat exchange and temperature as a function of the extent of the reaction as part of the total design problem. Even though the brief encourages such a point of view, students rarely obtain a global perspective until the 3rd session. Moreover, they are not infrequently misled into confusion over forward and back reaction rates.

About half the students start out by subscribing to a step-by-step, "system assembly" point of view: they feel they ought to arrive at a general design by articulating clear cut parts, such as "forward rate for a component reaction" (a couple of students have paid lip service, at least, to a "flow chart" design technique). With one possible exception the experts have been aware that this paradigm, though valuable, is not directly applicable for a problem of this complexity and refer at once to pictures of the application domain (frequently developed by students at a later stage). It is not that you cannot put together a general design from partial designs; some people do so successfully. But in doing this it is essential to choose the "right" parts, ie parts that are representative and open to combination (the example cited, forward rate of a one component reaction, is not) and difficulties arise because inadequate parts are identified. In general, the identification of representative parts does depend upon a global picture (this would not be so for a trivial task, in which the right parts are "given".)

Such pictures are a crucial ingredient of successful design performance but may also be misleading. For example, subjects fall into vicious circularity by failing to recognise that many of the mathematical expressions in the brief are tautologous transformations (they are all of them valid) and represent alternative ways of saying the same thing; this particular misconception could be, and ultimately is, remedied by envisaging reaction kinetics and equilibria as real physical chemistry, rather than the text book mathematics of chemistry. In any case, this

particular confusion leads subjects to compute the equilibrium constant (K) as a function of Temperature (T) and, at the same moment, to compute Temperature (T) as a more or less sophisticated function of its own argument in the original design. Experts tend to avoid or minimise this kind of mistake; presumably, they are more alive to the hazards of design. However, the student designers seem to learn rapidly from making mistakes of this kind and to transfer their experience to avoid other possible circularities in the design.

Both expert designers and student designers have trouble over the role of approximation. It is shown in the brief that Temperature (T), as computed in the required simulator, is a "trick" variable. All that is demanded is a T function that satisfies certain inequalities and changes in the right direction except for a critical region where more accuracy is demanded. This is an unavoidable consequence of modelling a complex physical chemical process in a simplified manner (in the team task, for instance, T computation is far more complex and the "trick" is uncovered by deeper examination of the processes). Subjects eventually come to terms with the limits of a simulation but do so in different ways with more or less direct reference to the application domain. Here, the use of valid analogical reasoning (Section 4) appears to be especially important.

Some general findings are as follows :

1). There is a significant positive correlation between versatility scores on the test of learning style and the extent to which subjects take account of the application domain; this probably correlates positively with any plausible index of design quality.

2). Students submit completed designs sooner than experts: they also make more self corrected mistakes (self correction because a circuit arrangement is found not to work satisfactorily)

than experts, and, consequently, backtrack more often. Backtracking takes up time but either inexperienced (student) designers learn rapidly from mistakes, or experienced designers are overly self critical, for the average total design time occupied by students is, as stated, less than the average for expert designers.

3). In interpreting these results, it is essential to recall that every design accepted as being completed must satisfy the brief and consequently various performance tests that are built into the brief. Looked at grossly, there are only a few final design types, though the details differ. The main and outstanding contrast is between the process of designing and the justifications or explanations offered by the subjects at various stages in the design task including, of course, their justification or explanation of the (acceptable) finalised design. There is no doubt that experts, not surprisingly, achieve greater elegance, but they take a longer time to do so and the effort may or may not (in this case we must rely upon the full analysis), be worthwhile.

4). Apart from the backtracking behaviour noted in (2) above, the crudely-observed consistent differences in style between student designers and experts, do not appear to be greater than the consistent differences between students or between experts (the within-group differences). These are reflected in and predictable from all the scores on the initial test for learning style (operation learning, comprehension learning and versatility).

5). Subjects with a high versatility score (and often with a high comprehension score) grasp certain features of the circuit itself and its relation to the application domain more rapidly than others. Amongst the student designers, this tendency shows up as more rapid backtracking (remedying mistakes, possibly; though, here, we must rely upon a detailed analysis, in recognising mistakes). It also shows up in terms of overcoming misconceptions about part of the application domain, (the interpretation of equations in terms of physical chemistry theory).

4. Analytical Reasoning, Insight and Innovation

One definite outcome of the research, even before detailed analysis is carried out, is that analogical reasoning is ubiquitous. The use and occasional misuse of analogy is frequent and in contrast to the exponents of an algorithmic model of design, a prominent part of both student and expert behaviour. Analogies may be recognised or abduced (invented) either within the circuitry which is designed or between components of the design and features or relations in the application domain. Insofar as there are many different kinds of analogy, for example, quite distinct analogies of form (or result) and analogies of method, this finding is not altogether at odds with those observers who emphasise the algorithmic/heuristic/systematic aspect of design (for instance, one kind of analogy of method is to recognise that an algorithm or operation used in one field, may be fruitfully employed in another, sometimes to achieve a similar result, when there is also an analogy of form, sometimes to yield a different, but still useful, result).

The finding is obtrusive. Probably the merit of versatility (noted in Section 3, 1) is chiefly due to the successful use of analogical reasoning by versatile subjects, in contrast to the misuse of analogy (abduction of similitudes that are trivial or are not valid) by the less versatile students.

In order to have confidence in such a finding, it is necessary to underpin it with a proper theory of analogies, their types, the difference between recognising and inventing them, etc. Such a theory exists, though it has not been exploited or discussed in previous progress reports. On my recent visit to Wright Patterson Air Force Base, in Dayton, Dr G Klein requested a technical account of the underpinning theory as part of the report sequence. Since the material may be of more general interest, the technical account of analogy is to be issued as a Scientific Note No 3 shortly after this Progress Report is submitted.

5. Versatility Training

Until a full analysis is available, the question of whether or not versatility training helps designers will remain open. On the face of it, we are unlikely to obtain a positive result for two reasons. One, which was anticipated as a possibility, is that few students competent to undertake the design task have a very low versatility score, so that differential sampling is a real problem. The other reason, just as strong, but not fully anticipated, is that the experimental method developed to exteriorise the design process, acts as a form of versatility training in its own right. Both students and experts are caused (in the analytic sessions, when designs are explained, or justified), to contemplate their own mental mechanisms and areas of strength and weakness. To do so systematically is part of versatility training so that, under these circumstances, the specific training would have to produce a very high magnitude effect in order to provide a significant comparative result. This is not evidence that versatility training, as such, is ineffective: rather that the lengthy monitoring procedure is a mild form of versatility training and that relatively short periods of intense training are likely to add relatively little to the overall performance.

6. Implications for Design Training

Two, commonly stressed, philosophies of design are noted in Section 4; one emphasising the systematic application of principles or operations or algorithms either for testing or transforming a partly completed design; the other emphasising the role of insight, innovation and some kinds of analogical reasoning. There is also a prevailing impression (rather than an assertion) that algorithmic skills and operations can be inculcated or improved by instruction, whereas little can be done to improve insight or analogical inventiveness. In view of this, the finding of Section 4 (that, when design is studied in depth, analogical reasoning appears as a dominant mode) might be misconstrued as a doctrine of despair.

It is wise to state, categorically, at this juncture, that we hold quite a different view. On the one hand, there does not seem to be a rigid demarcation between the design philosophies. Considered in sufficient detail (for example, by investigations that are designed to exteriorise normally unobservable aspects of cognition, hypotheses formation, and the like; ie. studies such as the present study), the heuristic/algorithmic and the innovative/analogical orientations are complementary rather than opposed. Surely, there are consistently different design styles but there is an algorithmic/heuristic and an analogical/innovative aspect to each competent style.

Next, we definitely deny that analogical reasoning and probably innovative reasoning (which does appear to be both commonly used and effective) is somehow unlearnable. Design training may have to be augmented to take account of this type of thinking, but it is no more nor less difficult to train people in the use of analogy (conversely, in avoiding the misuse of analogy) than it is to teach them helpful algorithms and principles. The belief, if it exists, that insight and analogy are ineluctable, is frankly mistaken and due to the lack, hitherto, of an adequate theoretical basis for analogical reasoning.

Either the theoretical basis outlined in Scientific Note No 3 or some equally precise statement, lead directly to

appropriate training expedients; possibly identical with "versatility training" or "Learning to Learn". It is true that positive recommendations are seldom encountered (presumably because of uncertainty about the mental mechanisms involved and the absence of a theory about what should be achieved). On the other hand, there is ample evidence that cogent training procedures can be instituted and that, when instituted, they are effective; the evidence in question comes from depth studies bringing individual differences into the picture, either those of other laboratories or our own.

7. Plans for Continuation of the Work

Individual and team studies are continuing and an adequate team task period is secured by item (a) in the work statement of the continuation proposal EOARD-77-046.

Scientific Note No 4 is due for almost immediate delivery and is partly typed at the moment. Progress Report No 8 will contain or refer to a detailed analysis, though greater refinement is possible under item (e) (evaluation study). In the meanwhile, sample analysis data will be furnished, together with a statement of the methods used in Scientific Note No 3.

As soon as possible we shall start work statement (c) (number of alternative designs, different but meaningful tasks) in order to retain members of the subject pool. For item (d) (comparison of system programming techniques), it is desirable to have at least some of the present subjects available, which bears directly upon the theme of Section 5 in the report. In contrast, item (b) (adaptive stylistic tests) and the finer points of item (e) have less urgency in this respect, though they are of comparable significance.

8. Material Due

Scientific Note No 3 and Scientific Note No 4 are
integral parts of this progress report. *Not received in DDC*
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